FINAL REPORT

MIXING ZONE EVALUATION: BP PRODUCTS NORTH AMERICA WHITING BUSINESS UNIT

Prepared For:
BP Products North America
Whiting Business Unit

Prepared By:
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January 2006

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1.0 INTRODUCTION

The present mixing zone evaluation review and data observation were undertaken at the joint request of the Indiana Department of Environmental Management (IDEM) and the BP Products North America, Inc., Whiting Business Unit (BP). The scope of work is in support of IDEM's review of BP's NPDES Permit renewal for a discharge into Lake Michigan. The purpose of this evaluation is to assess the current mixing zone application, and specifically provide a more accurate characterization of the receiving waters (Lake Michigan) in the direct vicinity of the discharge. The study focuses on determining the site-specific ambient currents at the proposed discharge location (Figure 1-1, identified as S3500) and using that data to develop appropriate scenarios to model the dispersion and mixing zone. As such, the dispersion modeling will more accurately simulate the conditions within the vicinity of the discharge.

Figure 1-1. Location of proposed discharge (S3500) into Lake Michigan, approximately 0.5 miles offshore and 1.3 miles southwest of Indiana Harbor.

This report presents the review of existing literature, data collection, data analysis, and provides recommendations for modeling input conditions. The report is organized and divided into the following main chapters:

- Chapter 2.0 presents the review of the previous submittals provided by BP to IDEM. The review is based on data and analysis presented in three (3) primary documents, and focuses on the characterization of the discharge-induced mixing zone.

- Chapter 3.0 presents the review of existing literature and data. This includes documents referenced by BP in their submittals, as well as additional studies performed over the more recent time frame (1998-2005). The review of the literature was focused on describing the currents near the discharge and the extent and duration of ice coverage.

- Chapter 4.0 presents the observed currents near S3500 collected from October 4, 2005 to November 19, 2005. Current data were collected throughout the water column. This chapter details the current data collection procedures, presents the observations and data analysis, and provides a summary of the existing current regime.

- Chapter 5.0 presents the attempt to correlate the current measurements to local wind observations. This includes the presentation of the local wind data, the correlation methodology, and the results of the correlation.

- Chapter 6.0 presents recommendations on defining a critical lake velocity and the recommended input conditions for the dispersion modeling.

2.0 REVIEW OF EXISTING MIXING ZONE SUBMITTAL

As part of the NPDES permit renewal application, BP Whiting submitted three (3) key documents to IDEM that were reviewed under this task. These included:

- a March 1998 (Volume IIR) report submitted for the NPDES Permit Renewal Application entitled "NPDES Permit Renewal Application: Mixing Zone Demonstration,"
- a January 1999 letter from Mr. Peter Beronio (BP-Amoco) in response to Mr. George Oliver (IDEM) containing responses to IDEM questions on the 1998 Volume IIR report,
- and an April 2002 (Volume IIR) report entitled "Revision and Update of NPDES Mixing Zone Demonstration."

Although additional documents were submitted to IDEM, the review was focused on these three key documents. These documents present the demonstration of the alternate mixing zone. In addition, the documents were reviewed in concert with the Indiana Administrative Code 327 IAC 5-2-11.4 pertaining to mixing zones and a Nonrule policy document from IDEM pertaining to mixing zones outside of the Great Lakes Systems (Appendix A). The overall review was geared towards the confirmation of the mixing zone analysis, with specific evaluation of the implementation of the modeling, determination of the physical processes, and assessment of the diffuser design.

2.1 DISCHARGE-INDUCED MIXING

In order to define the mixing zone, the dispersion achievable and the area defined by the discharge induced mixing were required. The computer model used to simulate the mixing and dispersion of the discharged water is called CORMIX (The Cornell Mixing Zone Expert System). CORMIX is used as a "decision support tool" in discharge assessments. As such, CORMIX is a software system for the analysis, prediction, and design of aqueous discharges into various water bodies. CORMIX is supported by the USEPA and is widely used and accepted by the environmental community. It uses a USEPA approved rule-based classification system to predict the geometry and dilution characteristics of discharges. The classification scheme places major emphasis on the near-field behavior of the discharge and uses length scales as measures of the physical processes.

CORMIX predictions have shown relatively good correlation with both laboratory and field experiments; however, these examples are limited to cases where discharge and ambient geometries, velocities, and density stratification are "simple" and consistent with test conditions that were applied to develop the empirical solutions embedded in CORMIX. CORMIX requires the following simplifications to represent mixing accurately:

- uniform rectangular discharge channel that may be bounded or unbounded laterally
- bathymetry with a relatively flat bottom
- linear shoreline
- ambient velocity parallel to the linear shoreline
- vertically and horizontally uniform ambient flow

- sufficient ambient flow such that stagnation (near zero velocities) does not occur.

The major emphasis of CORMIX is the near-field, discharged-induced mixing, where momentum and buoyancy dominate, applications that are aimed at determination of the near-field mixing zone are well suited for CORMIX evaluation. Flow behavior in the far-field, after boundary interactions, is largely controlled by the ambient conditions specified in CORMIX. Ambient conditions in CORMIX are simplified, and do not represent dynamic environments well. Therefore, in cases where far-field mixing is important, and the ambient receiving waters are sufficiently dynamic, CORMIX should not be directly used to evaluate far-field mixing.

For the discharged-induced mixing evaluation performed in the NPDES Permit Renewal Application, CORMIX does provide a good representation of the dilution and size of the discharge-induced mixing zone. CORMIX is a valid model for application in the Whiting Refinery discharge scenario (near-field) and can be used to define the discharge-induced mixing zone (DIMZ). Although the dynamic nature of the ambient currents within Lake Michigan is not adequately represented within CORMIX, momentum and buoyancy processes dominant the dilution in the near-field. For this application; however, CORMIX should not be used to determine the far-field mixing zone. When the ambient current distribution becomes the dominant mixing process in the far-field, CORMIX cannot accurately identify the nature of mixing within this environment.

2.2 WIND DATA

In order to develop current conditions within the vicinity of S3500, the BP submittals utilized a wind data set from Midway Airport recorded during 1965-1974. Although this may likely have been the nearest available source of data during the initial analysis, the inland location of Midway Airport can result in some errors in the statistical analysis. Typically, physical oceanographers prefer to obtain over-water winds, not influenced by frictional and topography effects, to develop wind-driven currents. These over-water winds are not influenced by, and are more representative of, current driving forces. However, in many cases, over-water winds are not readily available or easily attainable for development of wind-generated currents. Therefore, the closest available data should be used to provide the most statistically accurate, and the data least influenced by topography. During the initial mixing zone demonstration, Midway Airport was likely a reasonable source of wind information, providing an estimate of the wind magnitude and direction.

Additionally, a more contemporary wind record would be more representative of the wind statistics. Recent work on storm tracks through the Great Lakes Basin (Meadows et al., 1997a; Meadows et al., 1997b and Wood et al., 1995) indicate that during the time period of 1975-1994, there has been a northward shift of January cyclones. This long-term shift in cyclone path has a greater influence on wind and wave energies within the Lake Michigan basin. As the fetch length increases, it will also impact the average wind statistics as a different portion of the cyclone will pass over the recording station and result in a different long-term statistical average. Therefore, there has been a significant shift in the wind statistics over the last 30-40 years in the Lake Michigan Basin. More recent wind data would be recommended for use in developing the wind-induced currents.

This report uses more local and contemporary wind data collected at the Whiting Refinery to evaluate wind/current interaction and gauge the viability of using wind data to predict site-specific current information at the discharge location. The wind data is presented in detail in Chapter 4.0.

2.3 WIND TRANSFER FUNCTION

The mixing zone demonstration documents used wind data (Midway Airport) to generate currents near the discharge. In determining the amount of energy transferred from the wind to the surface current, the 1998 NPDES Permit Renewal Application applied a general engineering rule and multiplied the wind speed by one-thirtieth (1/30). This transfer rule does not agree with standard coastal and oceanographic methods for wind-induced currents.

The circulation within Lake Michigan is primarily produced by the wind stress acting on the water surface and by buoyancy (e.g., heat) fluxes between the water and atmosphere (thermohaline circulation). The wind stress induces wind-driven circulation, which is the primary current producer within Lake Michigan. Although there are other factors that influence the circulation within the lake (temperature, area, depth, coastline interference, wind blocking, etc.), the wind driven flow is by far the more energetic. For the most part, this wind driven current resides in the upper portion of any water body. The wind stress produces Ekman Layer (Ekman, 1905) transport in the surface layer (upper 100 to 200 meters) of the lake, induces horizontal pressure gradients, and initiates the wind driven geostrophic currents. The currents are for the most part geostrophic, meaning that the horizontal pressure gradients are balanced by the Coriolis Force. Ekman (1905) has explained quantitatively the wind-driven current in the Ekman equations:

$$fv_E + A_z \frac{\partial^2 u_E}{\partial z^2} = 0$$

$$-fu_E + A_z \frac{\partial^2 v_E}{\partial z^2} = 0$$

where u_E and v_E are the Ekman velocity components associated with vertical shear friction, f is the Coriolis parameter, and A_z is the kinematic viscosity. In order to obtain numerical relationships between the surface current, V_o, and the wind speed, W, Ekman arrived at the following:

$$\frac{V_o}{W} = \frac{0.0127}{\sqrt{\sin|\phi|}}$$

where W is the wind velocity in m/sec and ϕ is the latitude (only valid in regions outside of ±10º from the equator). This can also be related to depth (D_E) to calculate the velocity at any depth below the surface by:

$$V_o = 0.79x10^{-5} \frac{W^2}{D_E|f|}$$

$$D_E = \frac{4.3W}{\left(\sin|\phi|\right)^{1/2}}$$

For the case of surface currents in the Whiting region of Lake Michigan, a latitude of 41.73º should be used to obtain the transfer function. At this latitude, the relationship between the wind magnitude and the surface current is determined to be 0.01557 (approximately 1/64). As such, the wind speeds should be multiplied by approximately 1/64 to obtain a measure of the surface currents.

2.4 WIND/CURRENT INTERACTION

Another component of wind driven circulation is the relationship between the direction the wind is blowing and the flow direction of the currents that are produced. As presented in the 1998 NPDES Permit Renewal Application, the mixing zone demonstration assumed that lake currents were directed in the same direction as the wind. For example, since the wind analysis indicated that the predominant wind direction at Midway Airport was from the south, then the lake currents were also assumed to be from the south (to the north). However, applying Ekman's solution, the components of current flow are given as:

$$u_E = \pm V_0 \cos\left(\frac{\pi}{4} + \frac{\pi}{D_E} z\right) \exp\left(\frac{\pi}{D_E} z\right)$$

$$v_E = V_0 \sin\left(\frac{\pi}{4} + \frac{\pi}{D_E} z\right) \exp\left(\frac{\pi}{D_E} z\right)$$

where the u component is positive in the northern hemisphere and negative in the southern hemisphere. To simplify this for surface currents (z=0), the equations become:

$$u = \pm V_0 \cos 45^o \,, v = V_0 \sin 45^o$$

producing (in the northern hemisphere) a current direction that is 45º to the right of the wind direction on the surface. Figure 2-1 graphically indicates how the surface current is directed to the right of the wind by 45º, and the change in the direction throughout the water column (Ekman Spiral).

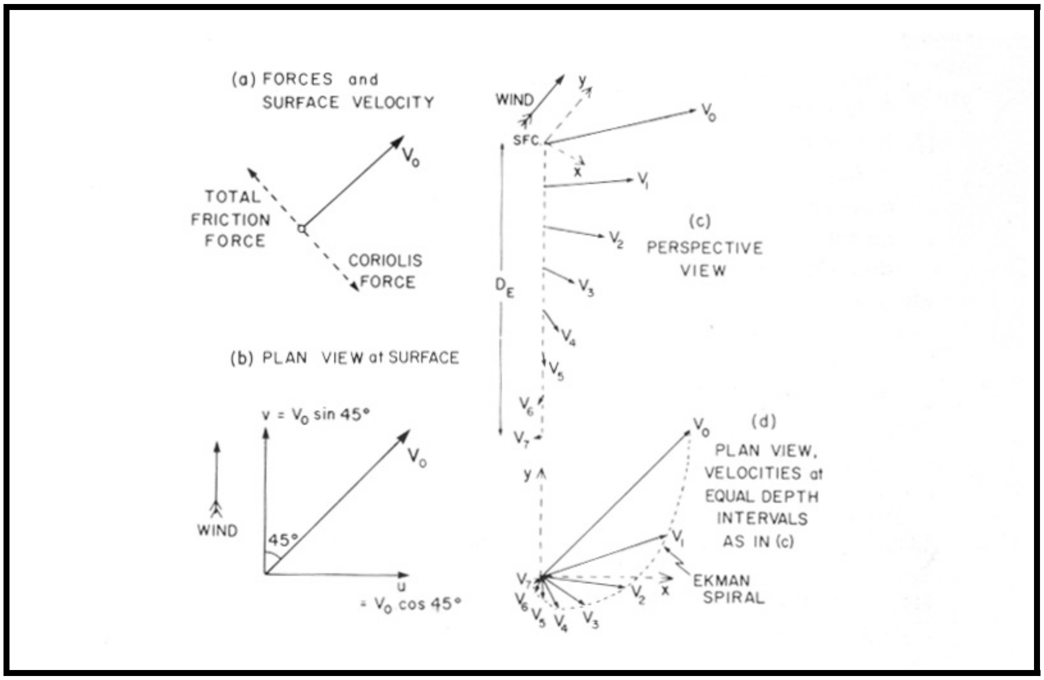

Figure 2-1. Wind-driven currents from Ekman analysis: (a) net frictional balances; (b) wind in y-direction and associated surface velocity components; (c) perspective view showing velocity; (d) plan view of velocities (Pond and Pickard, 1993).

One major impact that is not accounted by the Ekman analysis is the influence and proximity of boundaries (coastlines). Coastlines produce a shore-normal pressure gradient that tends to align the currents in a shore-parallel direction. The inclusion of coastlines into a current analysis makes the issue more complex than normally experienced in open water environments. The Whiting region shoreline is significantly complex, with the influence of Indiana Harbor. Therefore, there is a need for direct current observations beyond applying standard Ekman theory.

In addition, the use of a surface current to represent the ambient current field in a case of a bottom mounted diffuser is likely an overestimate. Surface currents are considerable higher than the currents located throughout the rest of the water column, and certainly higher than the currents directly at the lake floor. It is recommended that a depth-averaged current be used for representation of the ambient current flow at the proposed S3500 location.

2.5 DIFFUSER DESIGN

The mixing zone demonstration also presented the design of the proposed diffuser for the discharge. A criterion was applied to maintain a specific port exit velocity at the average effluent flowrate. The USEPA recommends maintaining a port exit velocity of 10 ft/sec for rapid mixing. This is the engineering standard used in designing multiport diffusers. As the average effluent flowrate changed between the 1998 and the 2002 NPDES Permit Renewal Application, the diffuser design was updated for the flowrate. Both selected diffuser designs adhered to the USEPA port exit velocity criterion and were adequately sized, spaced, etc. The orientation and configuration of ports (e.g., directed laterally, upward, etc.) should be evaluated based on the results of the current observations and recommendations provided in Chapter 5.0 and the results of the updated CORMIX modeling simulations.

2.6 CORMIX IMPLEMENTATION

The overall implementation of CORMIX in the mixing zone demonstration was also evaluated. Under the existing regulations, pursuant to 327 IAC 5-2-11.4(b)(4)(A), IDEM mandates that the dispersion at the edge of the Discharge Induced Mixing Zone is the limiting criteria for mixing zone delineation. CORMIX outputs the dispersion at the edge of the Jet Entrainment Zone, which is comparable to the Discharge Induced Mixing Zone and is therefore an acceptable method to determine the dilution at the edge of the Discharge Induced Mixing Zone. Models are only as good as the quality of the data used to specify the input and boundary conditions. Therefore, the performance of CORMIX heavily relies on the ability to select accurate input conditions and scenarios that represent the ambient conditions at the site-specific location in Lake Michigan.

As part of the mixing zone demonstration, a computed surface current of 0.18 m/s derived from the predominant wind directional band, and average wind speed within that band, was used to define the ambient current. Upon comparison to reports containing lake velocities, the current was reduced to 0.10 m/s, and considered a conservative estimate.

Due to the limitations in observed data available at the site-specific location, as well as some of the improvements in the analysis techniques presented above, the ambient current input used in the existing mixing zone demonstration should be adjusted. The following chapters of this report focus on developing accurate input conditions and scenarios to more accurately represent the site-specific conditions at the S3500 location.

3.0 EXISTING LITERATURE REVIEW

Circulation patterns and currents in Lake Michigan have been studied quite extensively over the past 40 years. In general, it has been found that the circulation in the lake is mainly wind-driven while the earth's rotation, bottom topography, and vertical thermal structure may also have an effect on currents, to a lesser extent. Close to the shore, convection and a shore-normal pressure gradient, or the set-up of wind-driven waters, can also affect the current regime (Mortimer, 1971).

The basic features of the thermal structure in Lake Michigan include a spring thermal bar, full stratification during summer months, a deepening of the thermocline during the fall cooling, and an overturn in the late fall. Large-scale circulation patterns tend to be cyclonic (counter-clockwise). The currents are found to be stronger and more organized during the winter when wind stresses are greater and there is less stratification (Beletsky and Schwab, 2001). The density-driven currents that occur from spring to fall help to complicate the lake hydrodynamics. In addition, ice-coverage in the lake is known to affect circulation patterns during the winter months.

Currents in the southwestern portion of the lake near the point of interest are of course largely affected by the overall circulation patterns in the lake. The currents at the location, being close to the shore, will also be affected by the aforementioned convection processes, the cross-shore pressure gradient, and by the shoreline orientation and features in the area. In particular, the discharge area is approximately 1 km from a northwest-to-southeast oriented shoreline and 1 km from a land feature to the southeast that protrudes into the lake and obstructs flow at the Indiana Harbor Canal. To the northeast, the alongshore flow is again obstructed by a breakwater extending into Calumet Harbor. The proximity to these features and the existence of ice-coverage in the winter months complicates the current regime in the area, which has required further studies of the circulation patterns.

The scope of work for Task 2 involved a literature review to gain a better understanding of circulation patterns and ambient conditions in the southern basin of Lake Michigan near the point of discharge. Documents referenced by BP for estimating lake currents in the region were first studied in order to ascertain their applicability for determining the input conditions for a mixing zone analysis. Additional references from the past 10 years that help to quantify nearshore currents for the southern end of Lake Michigan were also sought out and reviewed. The task also involved researching the extent and duration of ice cover in the region and how that might affect the flow conditions in the lake.

In addition to the literature review, IDEM requested that Woods Hole Group evaluate Appendix G of the Combined Coastal Program Document and Final Environmental Impact Statement for the State of Indiana (NOAA, 2002) as well as results taken from Tetra Tech's TMDL model of Lake Michigan.

3.1 Review of BP References

The documents provided by BP that were referenced for estimating currents in Lake Michigan's southern basin included general discussions of the various forcing of currents and circulation within Lake Michigan's basins, as well as studies conducted near the region of interest where currents were either simulated or measured in field investigations. The review of these documents helped to assess the applicability of the currents used as input to the CORMIX model that analyzed the area of discharge-induced mixing. In determining the applicability of the documents that presented current data, the factors that were considered include: 1) proximity to point of discharge, 2) water depth at location of simulated/observed currents, 3) duration/season of period when currents were simulated/observed, 4) depth where current was simulated/observed, and 5) whether the currents were measured or simulated. Although all documents provided by BP were reviewed, only those that were deemed pertinent to defining ambient conditions near the region of interest are discussed in this report.

3.1.2 Current Measurements

A significant amount of fieldwork was conducted during the 1970's in the region of Calumet Harbor from the Indiana Harbor Canal (IHC) to Chicago's South Water Filtration Plant (Snow, 1974; Saunders and VanLoon, 1976; McCown et al., 1976; Harrison et al., 1977; McCown et al., 1978). This work was mostly focused on water quality in this area of the lake and the transport and dispersion of oily wastes discharged by flow from the IHC. In these studies, currents were observed in the Calumet Harbor region during the winter season for periods ranging from 2 days to 5 months. Measured currents ranged from 0 to 30 cm/s. Reported average current velocities were 1.5 cm/s for the region and 2.2 cm/s for the station closest to the point of discharge. A summary of these results is presented in Table 3-1. The currents were observed to be dominantly shore-parallel, either in the northeast or southwest directions.

Additional studies on the currents in southern Lake Michigan were completed in the 1980's. Gottlieb et al. (1989) made observations of currents during the years of 1982 through 1984 throughout the lake's southern basin. However, the current data presented by Gottlieb et al. (1989), although useful, is not representative of the conditions that may exist in the vicinity of the discharge. The closest station where current observations were made is 60 km from the lake's southern shore where the water depth is 75 meters. The shallow-depth effects and the effects of the shoreline on the currents would be minimal at this location. Bhowmik et al. (1991) completed a study of the nearshore currents just North of the area of interest between 1989 and 1990. The longest period of observation was 1 month during the summer of 1990 where the median bottom current measured at a water depth of 23 meters was reported as 2.6 cm/s. In addition, the currents were shown to generally move alongshore in a southeasterly direction.

3.2 Additional References for Estimation of Currents

To supplement the references provided by BP used to estimate ambient currents in the region of Lake Michigan close to the point of discharge, Woods Hole Group conducted a literature search to locate more recent studies of lake currents and additional information on ice-coverage in the area and its effect on circulation. The literature acquired by Woods Hole Group was focused on studies conducted in Lake Michigan's southern basin. A summary of the literature found on observed currents, modeled currents and the extent and duration of ice cover follows below.

Table 3-1. Summary of Lake Michigan current information obtained from BP references, listed by date of publication

Author, Year	Location	Time Period	Depth at Station (m)	Meter depth (m)	Reported current velocities (cm/s)
Snow, 1974	Calumet region (1 mi. from Inland Steel BW)	1973, Nov. - Dec.		6.1	Maximum: < 15
Saunders and VanLoon, 1976	4 km offshore of S. Chicago (5 stations)	1975, Jun. - Nov.	10.4	5.2	Minimum: 0 Maximum: 25
McCown et al., 1976	3 stations 4-5 km offshore of SWFP*	1976, Feb. 14-16	9.6 - 12.8	1m above bottom	Minimum: 0.2 Maximum: 15.0
Harrison et al., 1977	Between the IHC and SWFP*	1977, Jan. – Mar.	9.6	8.1	Average: 2.2 RMS=6
McCown et al., 1978	Between the IHC and SWFP* (4 stations 4-5 km offshore)	1977, Mar. – Dec.	9.6 - 12.8	1.5m above bottom	Average: 3 Maximum: 13
Gottlieb et al., 1989	S. Lake Michigan basin	1982, Jun.- 1983, Jan.	75	15	Maximum: < 10
Gottlieb et al., 1989	40 km offshore, just south of Grand Haven,MI	1984, May - Oct.	100	10	Monthly average: 0 to 6
Bhomik et al., 1991	3 stations off Wilmette, IL	1989, Sep. 19-Sep. 21	2 - 5	1m above bottom	Median: 1.1- 1.5 Mode: 1.0 - 1.3
		1990, Jun. - Jul.	23	1m above bottom	Median: 2.6 Mode: 2.4

*IHC is the Indiana Harbor Canal and SWFP is Chicago's South Water Filtration Plant

3.2.1 Current Measurements

Field data collection programs have continued since the 1970s to gain a better understanding of currents and circulation patterns in southern Lake Michigan. In 1976 the Great Lakes Environmental Research Laboratory (GRERL) conducted a comprehensive study of currents along a west-to-east transect bordering the lake's southern basin (Saylor et al., 1980). Additional studies were conducted in the 1980s along the western coast of the lake, offshore of Grand Haven, MI (Lesht and Hawley, 1987; Meadows et al., 1992). In 1980, Lesht monitored bottom currents near the Calumet/Indiana Harbor region at the northern edge of Indiana shoals (Lesht, 1989). Observations of coastal currents were also made outside of Milwaukee Harbor during the start of fall in 1993 and during the summer months of 1994 (Miller, 1997). Two additional comprehensive field collection programs were conducted in the mid- and late-1990s as part of the Lake Michigan Mass Balance Study (LMMBS) and the Episodic Events Great Lakes Experiment (EEGLE). The LMMBS studied currents across the southern portion of Lake Michigan from Milwaukee, WI to Muskegon, MI and down along the eastern coastline to St. Joseph, MI during 1994 and 1995 (Lou et al., 2000; Beletsky and Schwab, 2001). The EEGLE program measured currents at various depths along the southeastern coast from Michigan City, IN to St. Joseph, MI. (Rao et al., 2002; Beletsky et al., 2003; Rao et al., 2004).

The reported current data from each of these studies are listed in Table 3-2. In general, the current velocity observations made throughout the southern basin of Lake Michigan ranged from 0 to 28 cm/s with the larger currents being observed in the deeper portions of the lake. Average current velocities ranged from 0.6 to 15 cm/s. The study that was conducted closest to the S3500 discharge was the study by Lesht who monitored currents at Indiana Shoals 1 meter above the bottom, in a water depth of 10 meters during October and November of 1980. The current velocities reported by Lesht, as shown in Figure 3-1 ranged from 0 to 19 cm/s where by estimation from the time series, the average velocity was approximately 5 cm/s.

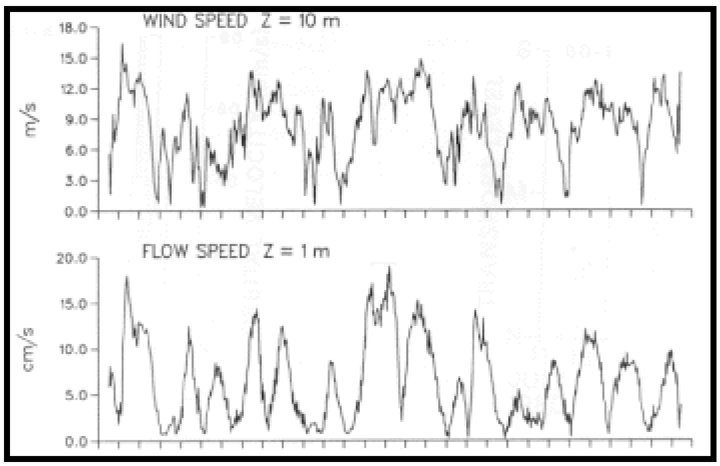

Figure 3-1. Time series of bottom current speed and wind speed observed in Lake Michigan from October 10th through November 7th, 1980 (Lesht, 1989).

3.2.2 Simulated Currents

Attempts have been made to numerically model the current field and circulation patterns that exist throughout the lake. Allender and Saylor simulated monthly average currents and temperatures in 1979, using a three-dimensional numerical model whose results were compared with observations made during June through October 1976. The modeled results were very similar to the observations. A more recent hydrodynamic modeling study involving Lake Michigan was focused on modeling lake-wide circulation thermal structure within the lake (Beletsky and Schwab, 2001). In this study, the currents and temperatures were simulated for the 1982-1983 and 1994-1995 time periods using a three-dimensional ocean circulation model (POM) that was subsequently adapted for use in the Great Lakes. The results from these simulations were compared with the observations taken from (Gottlieb el al., 1989) and the LMMBS. The model was successful at reproducing the annual cycle of circulation patterns and the inter-annual variability. The 6-month average currents reported in this study were 0.8 to 0.9 cm/s for May though October and 1.5-1.7 cm/s for November through April.

3.2.3 Ice Coverage

The extent and duration of ice coverage in the Great Lakes has been monitored and recorded by the GLERL for the past 45 years. A 30-winter (1973-2002) set of composite ice charts that combine observations from a number of different sources was digitized and statistically analyzed (Assel, 2003). The statistics computed from the set of ice charts include averages of the date of first ice, date of last ice and ice-cover duration. The average date of first ice (90% concentration) for southwestern Lake Michigan for depths of 0-20 meters was approximately January 15th. The average date of last ice (90% concentration) for southwestern Lake Michigan for depths of 0-20 meters was between February 15th and February 28th. The average duration of ice cover for this region is 30 to 45 days.

It has been reported that the current magnitudes in Lake Michigan under partial ice cover are markedly reduced (Miller, 1997). Very few studies have been conducted to investigate the effects of ice cover on circulation in the Great Lakes. A more general study was conducted where circulation patterns from numerical experiments were compared with theoretical predictions (Laval and Stocker, 2004). The simplified case of a long, narrow lake with wind stress applied along the long-axis of the lake was considered. The experiments showed ice-cover reduced the maximum currents observed in the lake by approximately 20% and 25% for the downwind and upwind cases, respectively. Currents were also reduced under ice cover in a separate study that involved a simulation of Lake Erie under partial ice cover conditions (Sheng and Lick, 1973). Therefore, if a valid long-term correlation can be established, ice coverage can be applied to any long-term correlated data by reducing currents during the January to February time frame by 20%.

Table 3-2. Summary of Lake Michigan current information obtained from supplemental references, listed by date of publication

Author, Year	Location	Time Period	Depth at station (m)	Meter depth (m)	Current speed (cm/s)
Allender and Saylor, 1979	Within 10 km of coast	1976, Jun.-Oct.	25 - 37	12.5	Average: 0.4-5.5 (N-S components)
Saylor et al., 1980	Rancine, WI to Holland, MI; Muskegon, MI to N. of Benton Harbor, MI	1976, May-Nov.	Variable	15-50	Average: 0-5 (May-Aug.) Average: 0-15 (Sep.-Oct.)
Lesht and Hawley, 1987	5km offshore of Grand Haven, MI	1981, 4 wks in Oct.	28	1m above bottom	Minimum: 0 Maximum: 28
Lesht, 1989	Northern edge of Indiana Shoals	1980, Oct.-Nov.	10	1m above bottom	Average: ~5 Minimum: 0 Maximum: 19
Meadows et al., 1992	Eastern coast, south of Grand Haven	1988-1992, Apr. – May		Top to bottom (ADCP)	Minimum: 5 Maximum: 15
Miller, 1997	2.5 km outside Milwaukee Harbor	1993, Aug.-Oct. 1994, May-Sep.	17	13-14	Average: 0.6 - 5
Lou et al., 2000	Near Muskegon, MI	1994, Nov.-Dec.[1]	28	0.5 m above bottom	Average: ~5 Minimum: 0 Maximum: 20
Beletsky and Schwab, 2001	Throughout Lake Michigan	1982-1983 1994-1995	Various stations		Average: 0.8-0.9 (May-Oct) Average: 1.5-1.7 (Nov-Apr)
Rao et al., 2002	Near Michigan City, IN	2000 winter[2]			Maximum (winter): 5
Beletsky et al., 2003	Near Michigan City, IN	Storm event: 3/9-3/12/1998[2]	20	12	Maximum: 25
Rao et al., 2004	Michigan City, IN to St. Joseph, MI	1998-2000, Winter-Spring[2]		10-12	Average (1998): 0.5-6 Average (1999): 0.8-4.6 Average (2000): 0.85-8

[1]Part of LMMBS
[2]Part of EEGLE

3.3 REVIEW OF COMBINED COASTAL PROGRAM DOCUMENT

The Combined Coastal Program Document and Final Environmental Impact Statement for the State of Indiana Appendix G (NOAA, 2002) is taken from the 1998 State of Indiana Coastal Situation Report (Purdue, 1998). The focus of the Coastal Situation Report is the impact of waves on the ever-changing Indiana shoreline. There is limited content regarding wind-driven currents as well as an analysis of the wind over the southern Lake Michigan basin. Appendix G focuses on the nearshore zone where the currents that are responsible for sediment transport are the wave-breaking induced currents. There is a discussion on previous current analysis projects in Lake Michigan, but these projects lacked focus on the nearshore zone. The wind analysis focused on wave generation potential of the offshore wind measured at NOAA Buoy 45007, which is located in the middle of Lake Michigan's southern basin. The wind data presented in the 1998 report is from 1981 to 1996. An issue with the NOAA buoy data set is that the buoy is removed during the winter (roughly December through February) to avoid ice damage. Therefore, the sample set is missing strong northerly winds that are dominant in the winter months. The wind rose presented in Appendix G (Figure 3-2) indicates an equal balance between occurrence of winds from the north and winds from the south. However, stronger wind speeds more frequently occur from the north.

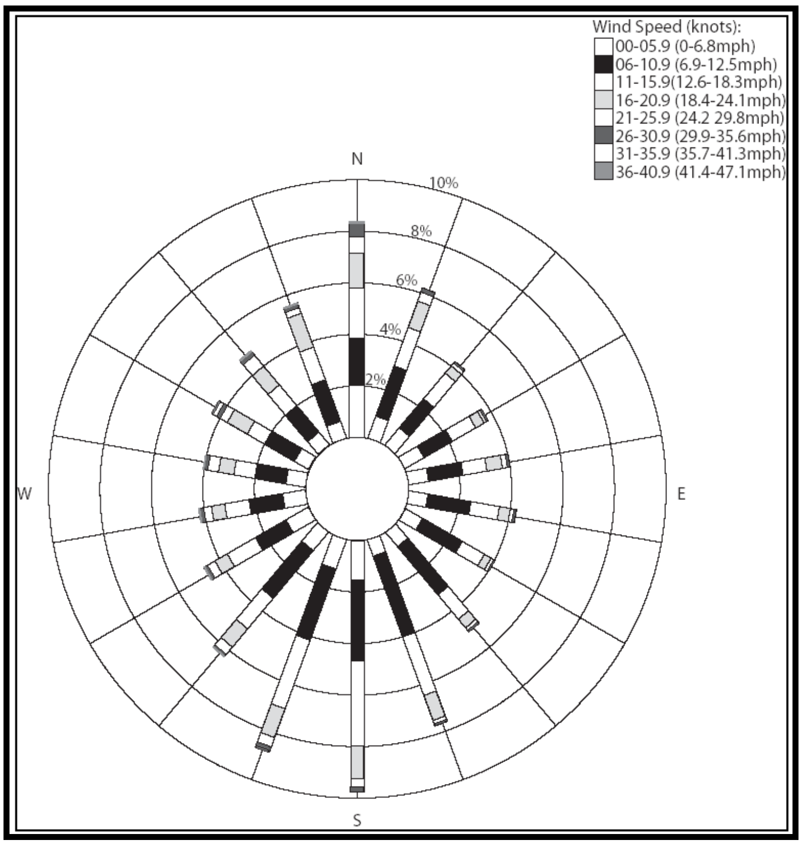

Figure 3-2. Wind rose of data from 1981-1996 recorded by NOAA Buoy 45007.

3.4 REVIEW OF RESULTS FROM TMDL MODEL OF LAKE MICHIGAN

The model used by Tetra Tech to solve for lake circulation is EFDC, which is a widely accepted and implemented model for water quality evaluations. The grid cell closest to the S3500 site is 39,17. Tetra Tech's original model output did not have data at this grid location, so they reran the model and saved output at this grid cell. The wind speed and direction information used for the model was from a weather station at Michigan City, IN. The model was executed from 3/31/1999 to 10/31/1999 or a period of 214 days. The model outputs velocity and depth data at hourly intervals. Figure 3-3 contains the modeled lake current at cell 39,17. The model is a single-layer, depth averaged current model and includes a net drift from West to East to approximate the long-term net current characteristics of the study area.

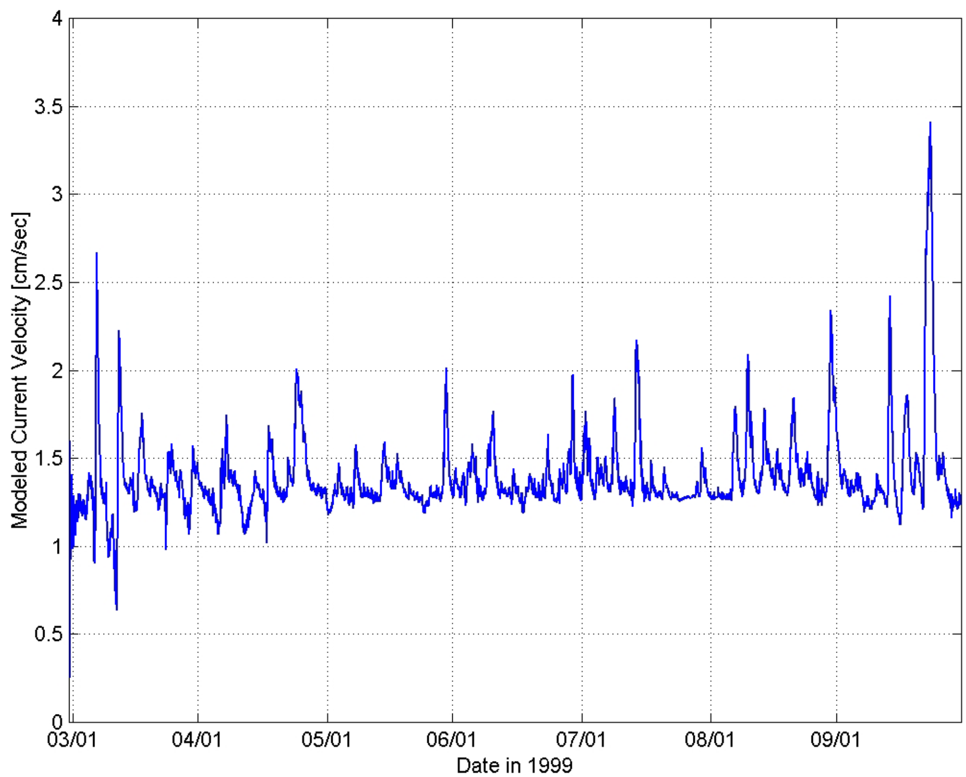

Figure 3-3. Modeled current velocity near S3500 location.

4.0 CURRENT OBSERVATIONS

4.1 EQUIPMENT DESCRIPTION

Current measurements were obtained with broadband, Workhorse Sentinel 1200 khz Acoustic Doppler Current Profilers (ADCPs) manufactured by RD Instruments of San Diego, CA. The ADCP is capable of high-resolution measurements of the spatial structure of current flow above (or beneath if downward looking) the instrument transducer. The ADCP measures currents using acoustic pulses emitted individually from four angled (at 20° from the vertical) transducers in the instrument. The instrument listens to the backscattered echoes from discrete depth layers in the water column. The returned echoes, reflected from ambient sound scatters (debris, sediment, etc.), are compared in the frequency domain to the original emitted pulse. The change in frequency (doppler shift) between the emitted versus the reflected pulse is directly proportional to the speed of the water parallel to the individual beam. For example, an echo of lower frequency indicates water moving away from the transducer while an echo of higher frequency indicates water moving toward the transducer. By combining the doppler velocity components for at least three of the four directional beams, the current velocities can be transformed to an orthogonal earth coordinate system in terms of east, north, and vertical components of current velocity.

Vertical resolution is gained using a technique called ‘range-gating’. Returning pulses are divided into discrete ‘bins’ based on discrete time intervals following the emission of the original pulse. With knowledge of the speed of sound, the discrete time intervals reflect the range (or depth) of each discrete bin from the transducer face. The accuracy of the current measurements can be compromised by random errors (or noise) inherent to this technique. Improvements in the accuracy of each measurement are achieved by averaging several individual pulses together. These averaged results are termed ‘ensembles’; the more pings used in the average, the lower the standard deviation of the random error.

For this study, the standard deviation (or accuracy) of current estimates (resulting from an ensemble average of 340 individual pulses) was approximately 0.5 cm/sec. The vertical resolution was set to 25 cm, or one velocity observation per every 25 cm of water depth. The first measurement bin was centered 0.79 m from the instrument, allowing for an appropriate blanking distance between the transducer and the first measurement.

4.2 INSTRUMENT DEPLOYMENT

Two (2) bottom-mounted 1200 kHz Acoustic Doppler Current Profilers (ADCPs) were deployed on October 4, 2005 (Figure 4-1). Marine and diving operations were conducted aboard the dive boat *The Marien “E”*. *The Marien “E*” is based out of Pastrick Marina in East Chicago, Indiana and the diving services were performed by Onyx Special Services, Inc. Each ADCP instrument was secured to the ocean floor using a trawl-resistant mooring system (Figure 4-2). The ADCP trawl mount was anchored to the sea floor via four (approximately 90-cm long) screw anchors. The screw anchors were attached at each of the four corners of the trawl mount and secured via shackle and chain. The ADCPs, when fitted in the trawl resistant mounts, measure approximately three (3) feet by three (3) feet by two (2) feet and have an in-water weight of approximately 350 lbs. The use of the trawl mount and the size of the Workhorse Sentinel ADCP result in the transducer head being located 48.3 cm off the sea floor. The ADCP's were deployed using a deployment harness and the vessel's over boarding boom and subsequently lowered to the lake floor via a combination of a wire cable and diving lift bags. Divers were employed to unhook the instrument system once on the lake floor, secure the location with the screw anchors, and to conduct a visual inspection to assure proper deployment of the instrument.

Figure 4-1. Deployment of one of the ADCP systems on October 4, 2005.

The proposed discharge site (identified as S3500 and at an approximate location of 87°28.093 and 41°40.976) is in approximately 25-30 feet of water and located 1.3 miles southwest of Indiana Harbor. A 1200 kHz Workhorse Sentinel ADCP was deployed at location S3500 (Figure 4-3). A second redundant system was deployed within the vicinity (within 50 feet) of the first system (Figure 4-3). The second system was lowered to the lake bottom and secured in the same manner as the primary system. The instruments were deployed for a total of approximately 45 days (October 4, 2005 – November 19, 2005) and there was 100 percent data return.

Figure 4-2. ADCP fitted in trawl-resistant bottom mount.

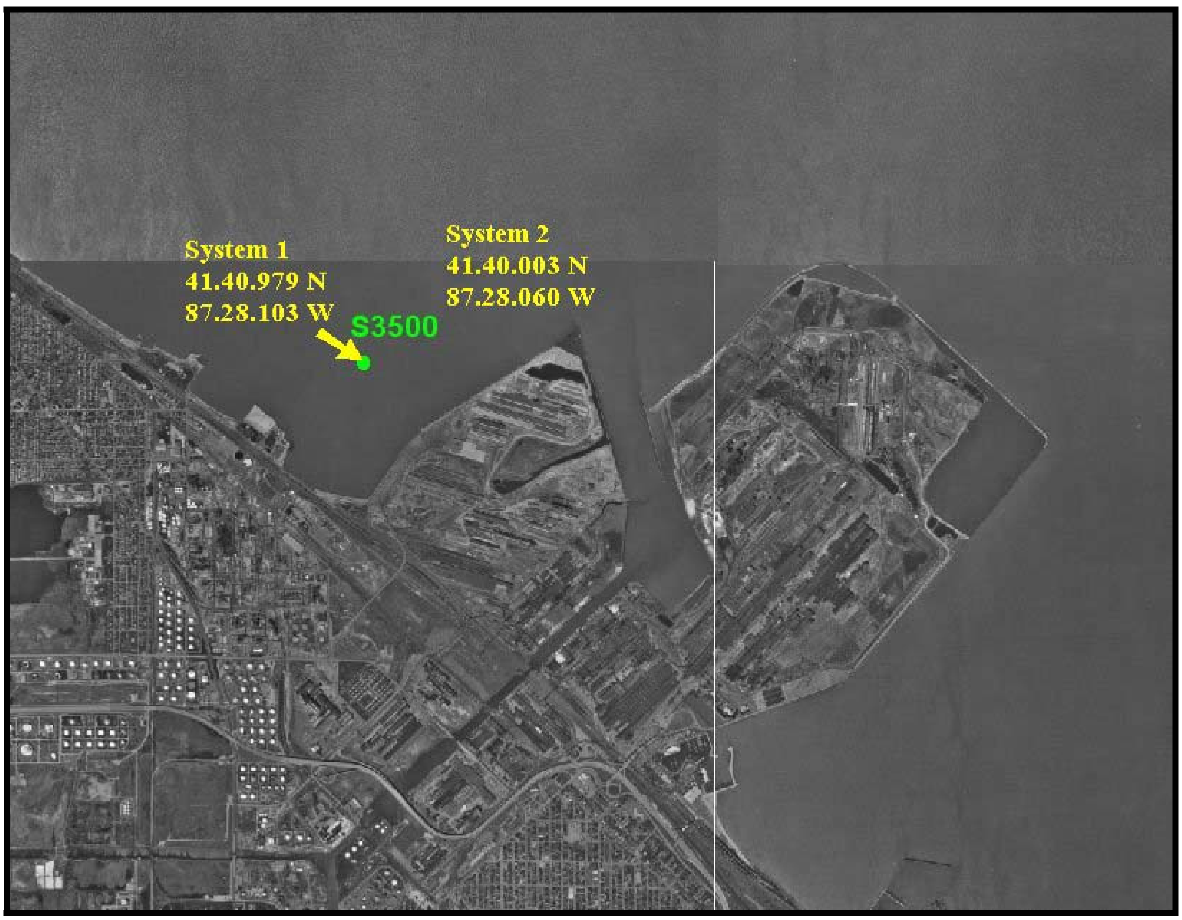

Figure 4-3. Location of ADCP systems deployed offshore of Whiting Refinery at station S3500.

4.3 CURRENT OBSERVATIONS

The ADCP data for each station consisted of velocity components at every depth bin for every ensemble. In addition, the raw ADCP (binary) files also include ancillary data such as correlation magnitudes, echo amplitudes, percent good pings, and error velocities (among others). These data can be used to recalculate velocities, as well as assure quality of the results. Each ensemble also includes header information such as the ensemble number, time of the ensemble, and water temperature. The raw ADCP data were converted to ASCII files using RDI's proprietary software to a user-defined data format. Velocity components (east-west and north south) were determined for each bin (25 cm) throughout the entire water column over the entire deployment period. The data sets for both systems were nearly identical. Therefore, only data from one system is presented within this report.

A color contour plot of the deployment period is presented in Figure 4-4. The color contour plot presents the measured conditions throughout the deployment period (October 4, 2005 to November 19, 2005). The pair of plots shows the spatial structure of flow through the water column at the S3500 location. Viewing the plot can offer a unique understanding of how the vertical structure of flow varies with time.

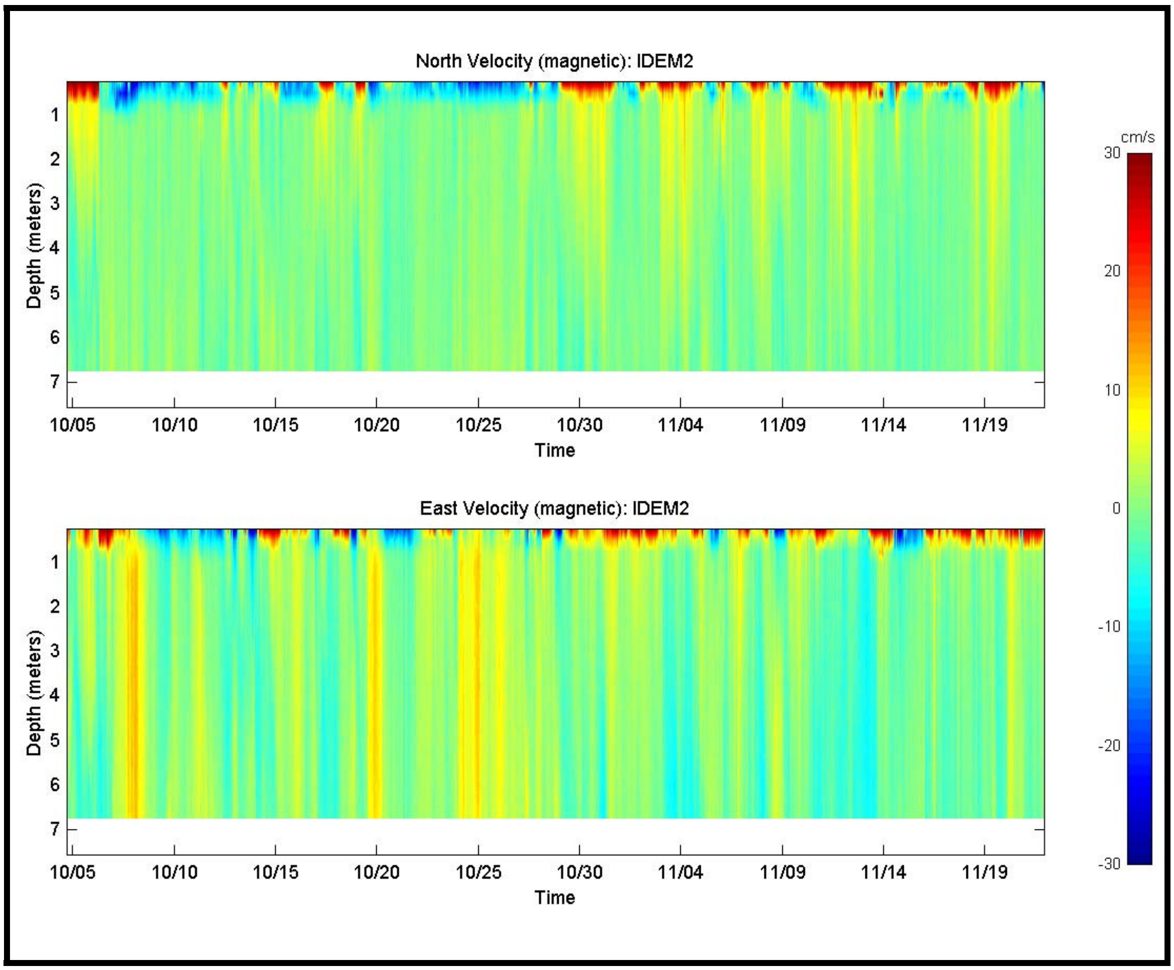

Figure 4-4. Color contour plots of north-south and east-west velocity during the deployment interval.

Figure 4-4 consists of two panels: the top panel presents the north/south component of velocity, while the bottom panel presents the east/west component of velocity. The directions are referenced to magnetic north. For example, positive north velocities represent water flowing in a northerly direction. Negative velocities represent water flowing to the south. Positive east velocities represent water flowing to the east; negative east velocities represent flow to the west. The vertical axis for each plot is depth (in meters), representing the depth of the water column. The horizontal axis represents time. The color bar on the extreme right of each plot indicates the magnitude of the north and east current velocities. Strong northerly and easterly flow is indicated by deep red; strong southerly and westerly flow is indicated by deep blue.

Although data are available throughout the entire water column, CORMIX only allows for input of a single velocity value for the entire water depth. Therefore, the current data were depth-averaged for each ensemble (10 minutes). The vertical average of each ensemble consisted of the mean velocity for all valid bins. Data recorded for the upper-most bins in the water column can be contaminated by side lobe reflections from the transducer and surface waves. At times, the measurements can be invalid. The validity of the upper bin measurements was determined by comparing the standard deviation (std) of upper values to the standard deviation of mid-column measurements. If the std at the bottom was more than twice the std of mid-column measurements, the upper bin was discarded from the depth-average. If the upper value was within the limits defined by adjacent measurements, the value was included in the calculation. In addition, a linear extrapolation of velocity from the transducer head (first measurement bin centered at 0.79 m) to the sea floor was included. Since the ADCP cannot measure the water below the head, it is assumed the bottom layer is equivalent to the velocity in the first depth layer.

The depth-averaged current is the most representative current magnitude for consideration of a bottom mounted discharge, as buoyancy and momentum effects carry the water towards the surface. A surface current velocity would likely be an overestimate of the current magnitude, while a bottom current velocity may be an underestimate. Figure 4-5 presents the directional distribution of current speed (cm/s) data (illustrated using a current rose) throughout the deployment. The gray-scale sidebar indicates the magnitude of current, the circular axis represents the direction of current (going towards) relative to True North (0 degrees), and the extending radial lines indicate percent occurrence within each magnitude and directional band. The most common current direction is towards the East and East-Southeast. This direction also contains most of the strongest currents.

Figure 4-6 presents a histogram of the depth-averaged current speeds observed over the deployment. The low current portion of the histogram is well resolved by the observations. A longer observation time period would fill the high current portion of the histogram, but likely not change the distribution in the lower current portion. Since dilution calculations are primarily concerned with lower currents, so the histogram presented in Figure 4-6 is likely adequate for meaningful dilution calculations. The probability density function (PDF - basically a smoothed version of the histogram) is presented in Figure 4-7. The PDF presents the current speed (x-axis) in terms of cm/s versus the percent occurrence (y-axis). The figure also provides some basic statistics of the depth-averaged current speed; including the mean, the 50th percentile, the 10th percentile, and the 90th percentile.

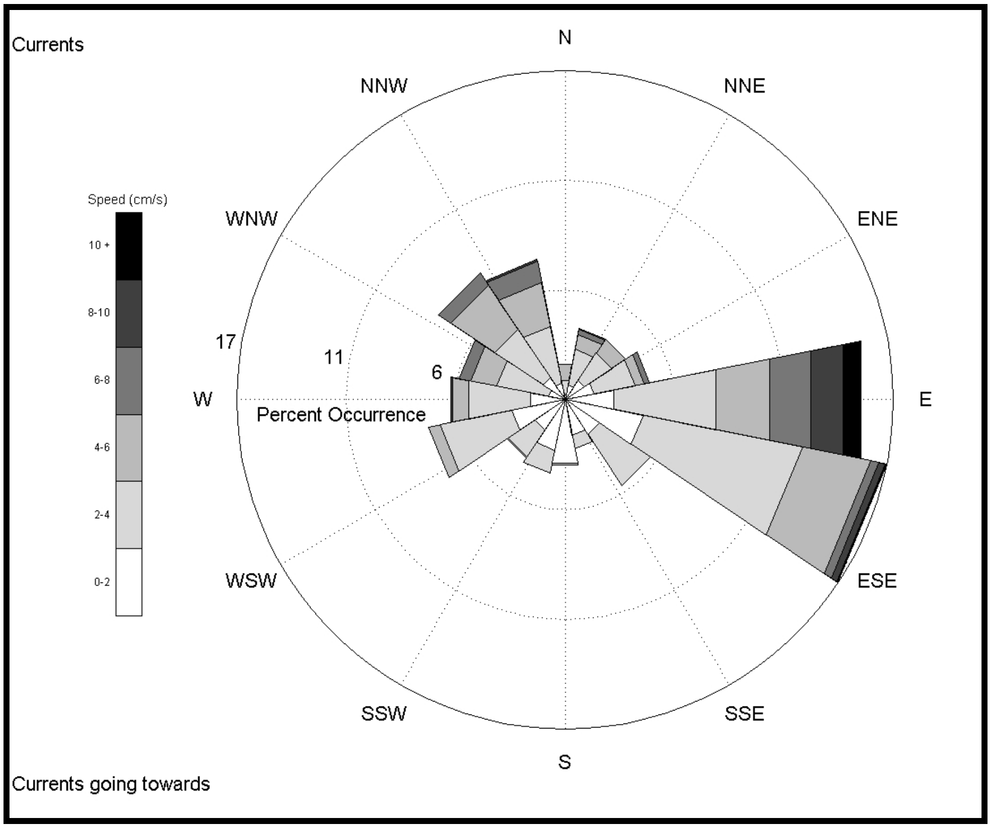

Figure 4-5. Current rose of current speed over deployment time period (October 4, 2005 – November 19, 2005).

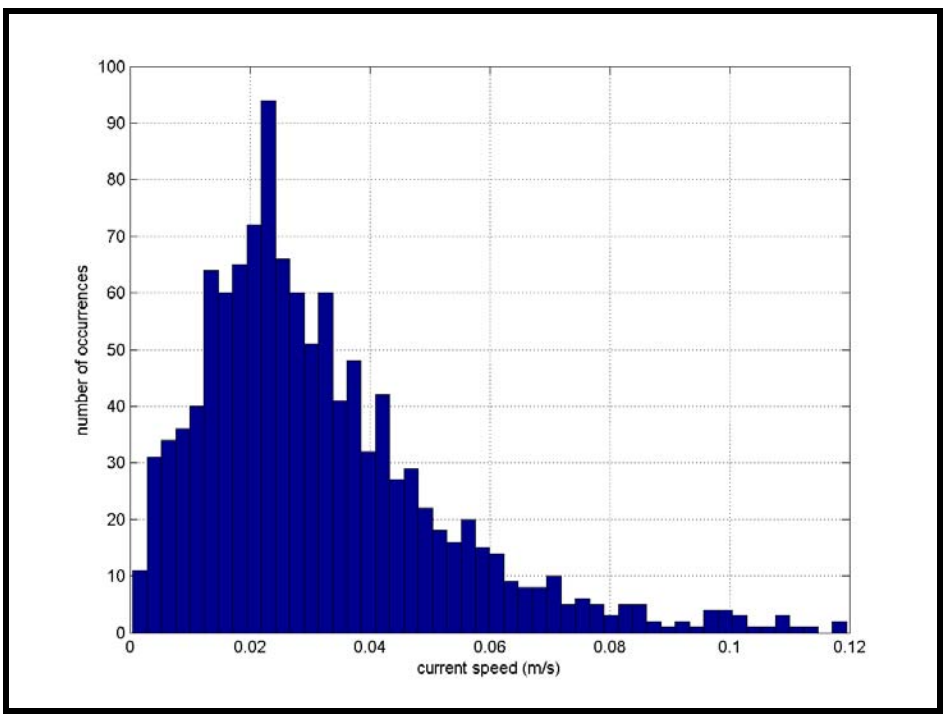

Figure 4-6. Histogram of current observations. Number of occurrences is presented on the y-axis, while the current speed (m/s) is presented on the x-axis.

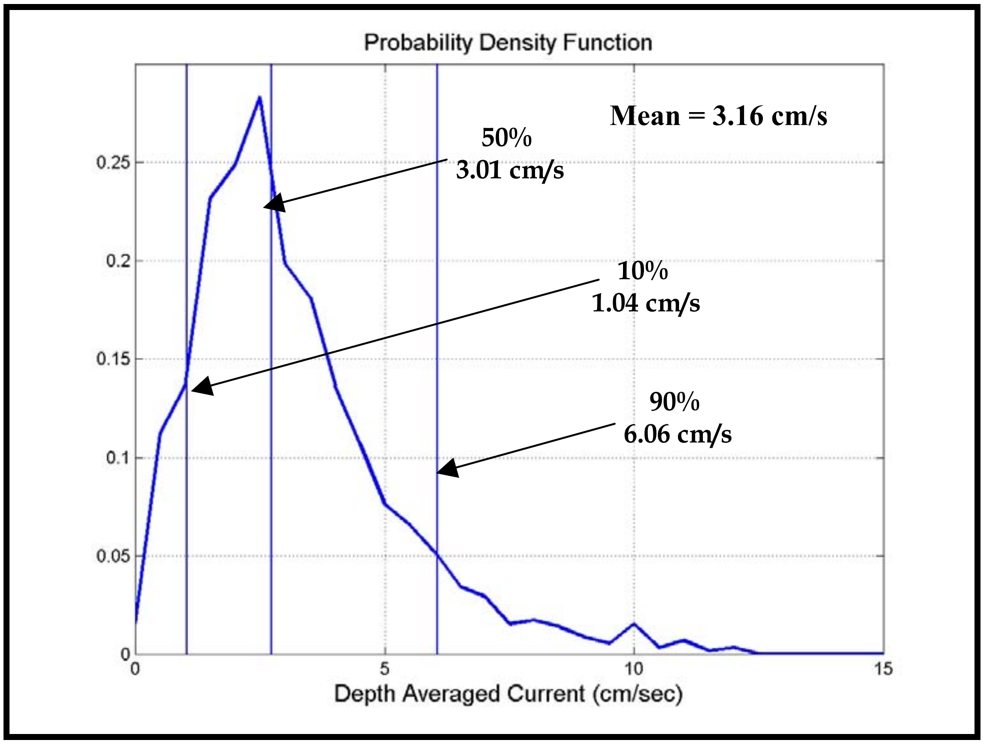

Figure 4-7. Probability density function of current observations.

5.0 WIND AND CURRENT CORRELATION

In order to potentially obtain a longer record of current data, correlations between local wind observations and the current observations were attempted. Wind observations were available at a variety of locations (Midway Airport, Gary Airport, BP Lakefront - Whiting Refinery, and NOAA Buoy 45007) during the deployment. Due to proximity to the discharge location and relative unobstructed observation ability, the BP Lakefront wind data were selected for potential correlation. As a secondary correlation, the offshore NOAA Buoy wind data were used.

A wind rose of the BP Lakefront data (at Gate 36 in the refinery) is presented in Figure 5-1 for both the deployment period (left panel) and from 2001-2005 (right panel). The gray-scale sidebar indicates the magnitude of current, the circular axis represents the direction of current (going towards) relative to True North (0 degrees), and the extending radial lines indicate percent occurrence within each magnitude and directional band. The similarity between the figures indicates that the deployment period is reasonably representative of a longer time period. Although there are some differences in the SSW and N bands, a majority of the wind distribution is similar. This similarity over the different time spans indicates that even if a correlation is possible, the distribution of the currents will be similar to those observed over the 45 day deployment (October 4 through November 19, 2005). Comparing the probability density functions over each of these time periods also reveals similar distributions. Therefore, it is reasonable to assume that the short-term observations are a reasonable measure of the currents at this location.

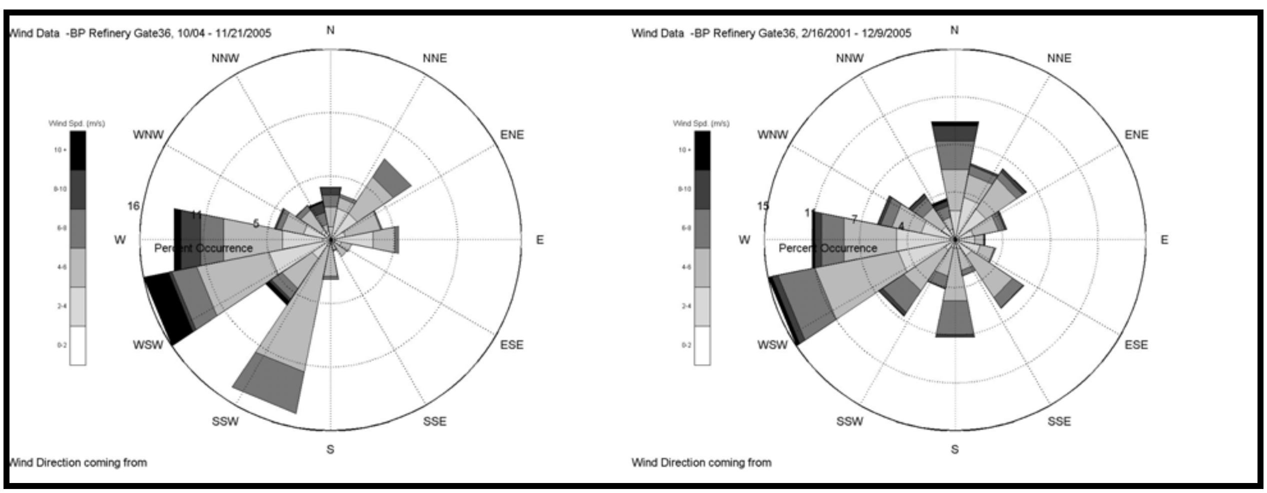

Figure 5-1. Wind rose for BP wind data during deployment (left panel) and from approximately 2001-2005 (right panel).

In addition, due to the complex nature of the shoreline at this location (e.g., the influence of Indiana Harbor), it is unlikely that there will be a good linear correlation between winds and currents. Figure 5-2 presents a scatter plot of the wind data (left panel) and current data (right panel) over the deployment. Each marker on the plot represents a single data value (observation). The x-axis represents the east-west component of magnitude (either wind or current), while the y-axis represents the north-south component of magnitude (either wind or current). The scatter plot indicates that there is not expected to be a direct linear correlation between the winds and the currents at this location.

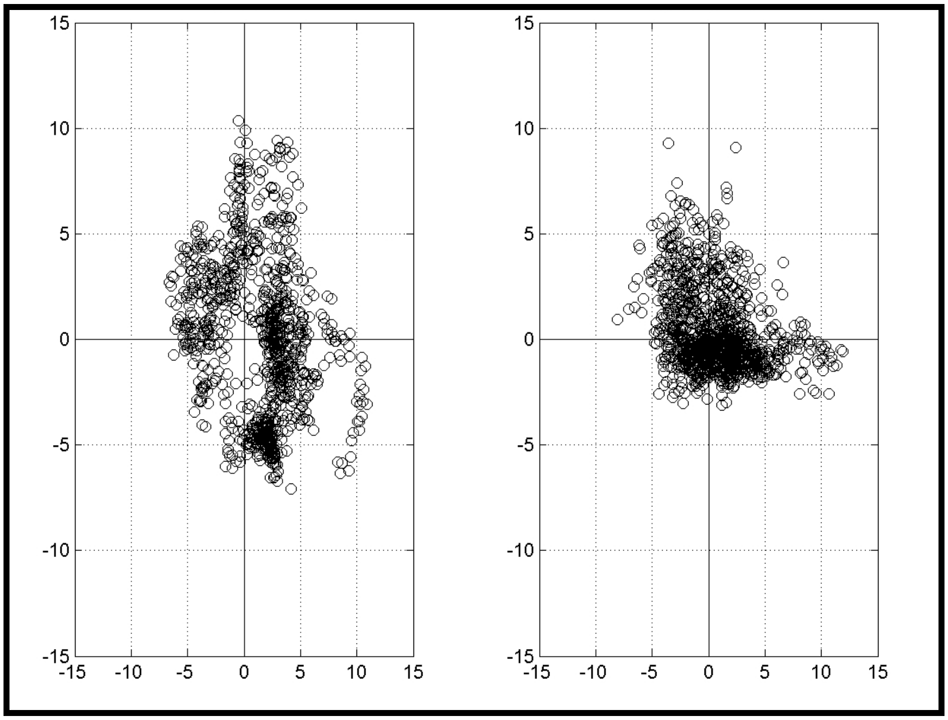

Figure 5-2. Scatter plot for BP wind data during deployment (left panel) and observed currents at site S3500 (right panel).

A variety of methods were applied to attempt to correlate the wind and current data. This included:

- A direct magnitude correlation between the wind and current speeds. This simplistic approach is a first step to identify if there is any correlation between wind and current speeds independent of direction. A technically defensible correlation could not be developed for the magnitudes.

- Ekman based correlation as a function of depth. This correlation methodology uses Ekman's equations (Chapter 2.0) to derive a correlation between the wind and currents (both in magnitude and direction). A technically defensible correlation could not be developed using Ekman's equations, primarily due to the significant influence of the complex shoreline on the current field.

- Physics based correlation by elimination of the cross-shore current component. This approach assumes that the alongshore component of the current is dominant and there is minimal cross-shore current. In many open coast cases, this is a good assumption. However, based on the scatter plot of current observations in Figure 5-2, there is a significant north-south component of current. As such, this type of correlation is not recommended due to both the lack of dominance in the longshore direction, as well as the complication caused by the non-linear shoreline extent near the Whiting Refinery and Indiana Harbor.

- Complex regression using u and v components of the wind and current observations. This method uses both the wind and current components (east-west and north-south) in the complex mathematical plane to perform a regression analysis. Again, no technically defensible correlation could be established using this method.

None of the correlation methodologies produced an r-squared value of more than 0.3 for either the BP Lakefront data or the NOAA Buoy data. The r-squared value is a statistical measure of how well the data can be correlated (i.e., how well a regression line approximates real data points). An r-squared of 1.0 (100%) indicates a perfect fit. Therefore, no technically accurate correlation between the wind and current data could be established. Due to the lack of correlation, a long-term current data set would introduce more uncertainties than using the observed data directly.

6.0 SUMMARY AND RECOMMENDATIONS

This report provides a review of the BP Mixing Zone Demonstration (2002) presented to the Indiana Department of Environmental Management (IDEM) for a discharge into Lake Michigan. In addition to reviewing the mixing zone application, site-specific ambient water currents were measured at the proposed discharge location to more accurately characterize the receiving waters. The water current observations are then used to develop more representative conditions and appropriate scenarios for modeling the dispersion and mixing zone.

The review of the existing mixing zone submittal consisted of assessing documents that were provided to IDEM as part of the National Pollutant Discharge Elimination System (NPDES) permit renewal application. The overall review was geared towards the confirmation of the mixing zone analysis, with specific evaluation of the implementation of the modeling, determination of the physical processes, and assessment of the diffuser design. The following provides a brief overview of the review presented in Chapter 2.0.

- CORMIX (Cornell Mixing Zone Expert System) was used to simulate the discharge and mixing into Lake Michigan. CORMIX is supported by the USEPA and is widely used and accepted by the environmental community. For the discharged-induced mixing evaluation performed in the BP NPDES permit application, CORMIX does provide a good representation of the dispersion and size of the discharge-induced mixing zone (DIMZ). The DIMZ comprises the near-field mixing zone, where momentum and buoyancy processes dominate, and is well suited for CORMIX simulation. In the far field, where the currents become more important, CORMIX is limited due to over simplification of the ambient conditions. Therefore, in cases where far field mixing is important, and the ambient receiving waters are sufficiently dynamic, CORMIX should not be directly used to evaluate far-field mixing. Since the DIMZ is the primary concern here, CORMIX is valid for this application.

- The wind data used in the permit applications were recorded at Midway Airport from 1965-1974. More local and contemporary wind data are recommended to evaluate the nature of the relationship, if any, between winds and currents at this site-specific location.

- The mixing zone demonstration used wind data (Midway Airport) to generate currents near the discharge through an energy transfer. The transfer function presented in the permit renewal application was not correct, and should not be applied to generate currents at the discharge location. Details can be found in section 2.3. In addition, the relationship between wind direction and the flow direction of the currents is incorrectly assumed in the permit renewal application. Discussion of wind and current interaction can be found in section 2.4.

- The permit application uses a surface current to represent the ambient current field. This is an overestimate of the ambient current, since surface currents are considerably higher than the currents located throughout the rest of the water column. It is recommended that a depth-averaged current be used for the ambient current flow at this location.

- The diffuser design presented in the permit application adheres to USEPA standards and is adequate. The diffuser design (configuration and orientation of ports), however, should be updated based on the results of the updated dispersion model simulations recommended in this Chapter.

In addition, a brief review of existing studies and data observations was conducted as part of this study. Circulation patterns and currents in Lake Michigan have been studied extensively over the past 40 years. Although a variety of studies have been conducted, there were no significant data observations at the location of the proposed discharge. In addition, most of the previous data collection programs were focused on general Lake Michigan circulation and/or observed currents at a single water depth. Existing numerical models of currents within Lake Michigan provided supplemental information, but either did not provide current results at the discharge location, or provided inconsistent results compared to some of the historical observations. Therefore, in order to provide confidence in the nature of currents at the proposed discharge location, direct measurements were required.

Water current measurements were obtained from October 4 to November 19, 2005 every 10 minutes directly at the proposed discharge location. Although data are available throughout the entire water column, currents were depth-averaged since CORMIX only allows for input of a single velocity value for the entire water depth. The depth-averaged current is the most representative current magnitude for consideration of a bottom-mounted discharge, as buoyancy and momentum effects carry the water towards the surface. A surface current velocity would likely be an overestimate, while a bottom current velocity may be an underestimate. A probability density function was determined based on all the depth-averaged measurements made over the deployment period (October 4 to November 19, 2005). The mean depth averaged current magnitude was 3.16 cm/s, while the 10th percentile and 90th percentile current magnitudes were 1.04 and 6.06 cm/s, respectively. An attempt to extend the current data set was made by correlating current observations to long-term, local wind observations (details presented in Chapter 5.0). A statistically valid correlation between the wind and current observations could not be established.

Since the previous permit application lacked actual data observations of the ambient current at the proposed discharge location, the ultimate goal of the review and current observations was to assist in the development of a critical lake velocity and/or recommended input conditions for the CORMIX modeling effort. Based on the lack of a technically accurate correlation between the wind and current observations, it is recommended that the direct lake observations be used to define the mixing zone at the proposed discharge location (site S3500). These observations offer a significant improvement over the assumed ambient lake velocities used in the existing mixing zone demonstration (permit application), and are more defensible than a long term assimilated current data set with questionable statistical correlation. For this particular site, direct use of the current observations to develop ambient lake conditions are preferred over long-term assimilated (correlated) data or assumed data and are recommended for the following reasons.

- The measured current data (October 4 to November 19, 2005) resolve a reasonable histogram of current speeds, especially in the low current speed portion of the distribution. Since dispersion and mixing zone concerns are primarily concerned with time periods of low flow, the observed current data (October 4 to November 19, 2005) are useful for a meaningful dispersion analysis.

- The similarity between the short term (October 4 to November 19, 2005) and long term (2001-2005) wind distributions indicate that the short term observations are representative of a longer sample set. In other words, since the wind is similar over both the short-term and long-term, currents generated from the long-term wind data set would have similar statistics as the short-term observed currents. Therefore, the distribution of the observed currents (October 4 to November 19, 2005) is likely representative of the ambient currents at this location.

- The low r-squared values indicate the lack of correlation and therefore, utilization of direct measurements removes potential error associated with data assimilation of a long-term data set. The complex orientation of the site and the dynamic nature of the current field may introduce errors that are not representative when trying to assimilate a long-term data set. In essence, it is more defensible to use the direct measurements, than attempt to utilize a questionable correlated data set.

Table 6-1 presents the recommended scenarios for CORMIX simulation and to determine the mixing zone. The table provides some general statistics for each approach direction, as well as the percent occurrence of current within each bin. CORMIX should be simulated for each of the cases presented in Table 6-1 using the current direction and the mean depth-averaged current (gray column). Subsequently, based on the results of the CORMIX modeling, a magnitude histogram and a directional spread of the dilutions should be created. These results will correspond to the distribution of current observations and the percent occurrence of each mixing ratio can be determined (e.g., the percentage of time the mixing is under 40:1). Finally, these results can be used to develop a histogram or probability density function of the dispersion ratios that can provide design guidance/recommendations for diffuser orientation, design, and layout.

Table 6-1. Recommended scenarios for determination of the discharge-induced mixing zone and input for CORMIX. Depth-averaged current statistics.

CASE	Current Direction (Going towards)	% Occurrence	Max (cm/s)	Mean (cm/s)	Median (cm/s)	10% (cm/s)	90% (cm/s)
1	0	4.20	9.9	3.53	3.46	1.29	5.65
2	22.5	4.00	10.91	3.46	3.37	1.06	5.8
3	45	4.07	9.15	2.92	2.79	0.95	4.99
4	67.5	5.27	8.48	2.89	2.64	0.92	5.12
5	90	16.00	13.6	4.78	4.05	1.68	9.15
6	112.5	14.27	11.58	3.44	3.08	1.48	5.52
7	135	6.06	6.39	2.18	2.14	0.94	3.35
8	157.5	3.25	4.65	1.93	1.82	0.84	3.14
9	180	2.89	4.74	1.66	1.56	0.72	2.69
10	202.5	3.27	4.73	1.83	1.73	0.73	3.01
11	225	4.28	5.35	2.08	1.9	0.71	3.62
12	247.5	6.64	8.4	2.58	2.54	1.05	3.93
13	270	6.32	9.02	2.95	2.9	1.02	4.9
14	292.5	6.39	8.74	3.59	3.42	1.38	6.06
15	315	6.98	9.47	3.82	3.76	1.67	6.15
16	337.5	6.09	12.1	4.18	4.11	1.07	6.79

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8.0 APPENDIX A

The Indiana Administrative Code (IAC) in Section 11.4 provides for the governance of mixing zones within the Great Lakes. The following is the text from the IAC:

(A) Alternate mixing zones are granted on a pollutant-by-pollutant and criterion-by-criterion basis. Any discharger seeking a mixing zone other than that specified by subdivision (2) or (3) shall submit an application for an alternate mixing zone for consideration by the commissioner. The alternate mixing zone application must do the following:

(i) Document the characteristics and location of the outfall structure, including whether technologically-enhanced mixing will be utilized.

(ii) Document the amount of dilution occurring at the boundaries of the proposed mixing zone and the size, shape, and location of the area of mixing, including the manner in which diffusion and dispersion occur.

(iii) For sources discharging to the open waters of Lake Michigan, define the location at which discharge-induced mixing ceases.

(iv) For sources discharging to tributaries of the Great Lakes system that exhibit appreciable flows relative to their volumes and seeking an alternate mixing zone for an acute aquatic life criterion or value or for acute WET, define the location at which discharge-induced mixing ceases under stream design flow conditions.

(v) Document the physical, including substrate character and geomorphology, chemical, and biological characteristics of the receiving waterbody, including whether the receiving waterbody supports indigenous, endemic, or naturally occurring species.

(vi) Document the physical, chemical, and biological characteristics of the effluent.

(vii) Document the synergistic effects of overlapping mixing zones or the aggregate effects of adjacent mixing zones.

(viii) Show whether organisms would be attracted to the area of mixing as a result of the effluent character.

(B) The commissioner may grant the alternate mixing zone if the discharger demonstrates the following:

(i) The mixing zone would not interfere with or block passage of fish or aquatic life.

(ii) The level of the pollutant permitted in the waterbody would not likely jeopardize the continued existence of any endangered or threatened species listed under Section 4 of the ESA or result in the destruction or adverse modification of such species' critical habitats.

(iii) The mixing zone would not extend to drinking water intakes.

(iv) The mixing zone would not impair or otherwise interfere with the designated or existing uses of the receiving water or downstream waters.

(v) The mixing zone would not promote undesirable aquatic life or result in a dominance of nuisance species.

(vi) By allowing the additional mixing:

(AA) substances will not settle to form objectionable deposits;

(BB) floating debris, oil, scum, and other matter in concentrations that form nuisances will not be produced; and

(CC) objectionable color, odor, taste, or turbidity will not be produced.

(C) In no case shall an alternate mixing zone for an acute aquatic life criterion or value or for acute WET be granted unless the discharger utilizes a submerged, high rate diffuser outfall structure (or the functional equivalent) that provides turbulent initial mixing and minimizes organism exposure time.

(D) In no case shall an alternate mixing zone for an acute aquatic life criterion or value or for acute WET be granted that exceeds the area where discharge-induced mixing occurs.

(E) In no case shall an alternate mixing zone for a discharge into the open waters of Lake Michigan be granted that exceeds the area where discharge-induced mixing occurs.
(F) Upon receipt of an application for an alternate mixing zone, the commissioner shall provide notice, request comment, and, if requested, schedule and hold a public meeting on the application in accordance with section 11.2 of this rule.